Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 122 (2017) 769–774

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

PVopti – hourly based energy balance for building design

Bastian Burger[a]*, Monika Hall[a]

[a]*University of Applied Sciences and Arts of Northwestern Switzerland, Institute Energy in Building, St. Jakob-Strasse 84, 4132 Muttenz, Switzerland*

Abstract

PVopti is a freeware tool to calculate hourly energy balances for different building types. It is simple to use and it quickly calculates self-consumption for different designs. Load profiles according to SIA 2024 are used to distribute yearly values on hours. For demand of lighting a criterion for daylight is added. Compared with measurements of single family houses and apartment buildings, self-consumption calculated with PVopti shows very good agreement. Currently, a German version is available on www.minergie.ch, soon there will be versions for 4 languages (dt, fr, it, en).

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: Self-consumption, hourly based ernergy balance, tool, building design, electric storage, autarky

---

1. Introduction

Typically, in buildings with photovoltaic systems (PV) for electricity generation the building electricity demand and the on-site production is not directly congruent. Therefore, a part of the PV-generated electricity is fed into the grid and a part of the demand is covered by electricity taken from the grid (see Fig. 1). The current practice of using

---

* Bastian Burger, Tel.: +41 061 467 46 83;
E-mail address: bastian.burger@fhnw.ch

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.394

yearly based energy balances does not differentiate PV electricity in regard to self-consumption or self-sufficiency. With the increase of installed PV power, the discussion on volatile electricity generation, electric energy storage and grid-development, self-consumption gains more attention. The variation of demand and production over time can cause a major challenge for utility companies. For building owners, the economic viability and ecological balance are strongly influenced by self-consumption and self-sufficiency.

Focus on the mismatch between electricity demand and production in buildings led the leading Swiss label for buildings Minergie to experiment with monthly based energy balances for a selection of Minergie-A beacon projects in the year 2015. Several approaches based on monthly balances were discussed, none of which proved to be readily applicable. In terms of manageability and according to [1], energy balances based on an hourly time step are considered to be the best approach, overall. As part of subtask B of IEA EBC Annex 67, a methodology has been developed by the authors which allows calculation of electricity self-consumption with only a very limited set of information about the building. Based on this methodology, an hourly-based tool called “Enerflex” was developed. With Enerflex, variations in self-consumption can be rated in the (early) design phase with reasonable accuracy and cost.

On January 1st, 2017 Minergie launched new definitions of requirements. These are based on an hourly energy balance and a different weighting of on-site generated electricity for self-consumption and electricity fed to the grid. Minergie attempts to be the first label to take grid interaction into account as a design parameter for buildings. The authors were mandated by Minergie and the Swiss cantons to develop a public “self-consumption-tool” for practical application – “PVopti”. This tool is a toned down version of Enerflex geared to be used as part of the Minergie certification process. PVopti is an easy-to-use and freely available tool which can be used for most building types. The tool respects common heating systems, the main energy demands found in buildings and on-site electricity generation by photovoltaics and combined heat and power. Electricity storage can be included as well as demand side management.

As Swiss standards are also beginning to look at self-consumption, the tool may find additional use in the near future. The Swiss standard SIA 380 [2] already allows an hourly based energy balance, and the revised Merkblatt SIA 2031 [3] will demand an hourly based calculation of PV self-consumption.

Nomenclature

Self-consumption	PV electricity generated and simultaneously used to cover own demand [-]
Self-consumption ratio	Percentage of self-consumption on PV electricity [%]
Autarky ratio	Percentage of self-consumption on electricity demand [%]
Feed-in	PV electricity fed into the grid [kWh]
Feed-in ratio	Percentage of fed-in on PV electricity [-]

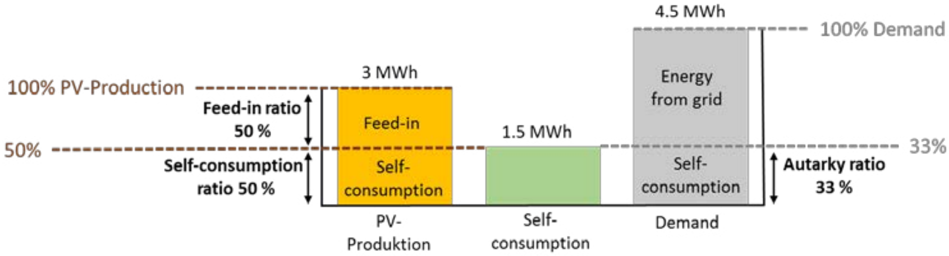


Fig. 1: Relation between self-consumption, feed-in and autarky and their ratio

2. Methodology and workflow

PVopti was developed to be used by architects, designers and engineers in the early stages of building design. Therefore, it has to be simple to handle and quick in use. Variations of a base design must be easy and the resulting effect on self-consumption must be displayed clearly.

In order to cause no additional work, calculations required for building codes anyway are used as input values. Additional standard values based on Merkblatt SIA 2024 [4] or on Minergie [5] are used. With progress in planning, more values from external calculations are available which can be used as input and can help increase the accuracy of the results of PVopti.

Once yearly or monthly input data are entered, hourly demand and production is calculated by using profiles according to [4], based on climate data (according to Merkblatt SIA 2028 [6]), SIA standards (e.g. SIA 380/1 [7]) and additional estimations. Electric storage or demand-side management is taken in to account on an hourly basis as well. Hourly results are aggregated to yearly a monthly values and displayed as numerical values and graphically (Fig. 2).

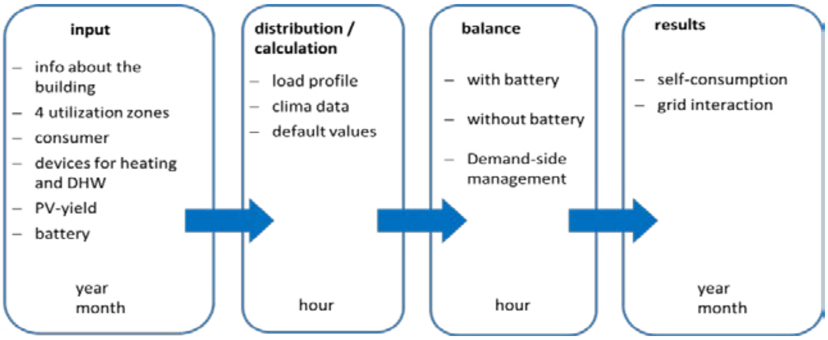


Fig. 2: Workflow of PVopti (DHW: domestic hot water)

For better usability only two sheets are visible to the user. Color codes guide through the input sheet: yellow cells demand input values (which will replace a standard value if proposed), green cells hold pull-down-menus to choose from (Fig. 3a). The result sheet displays values and graphics for grid-interaction, demand and production (Fig. 3b).

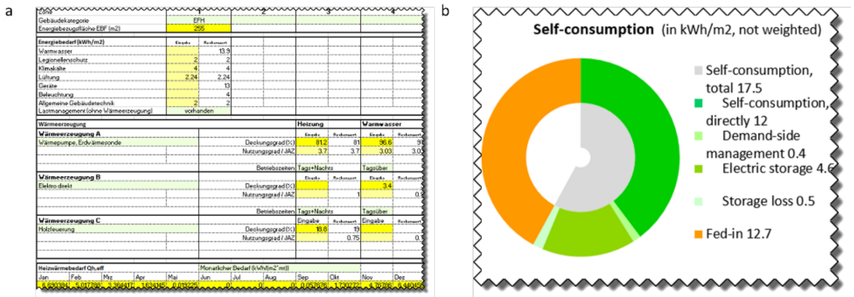


Fig. 3: Details of input sheet and result sheet

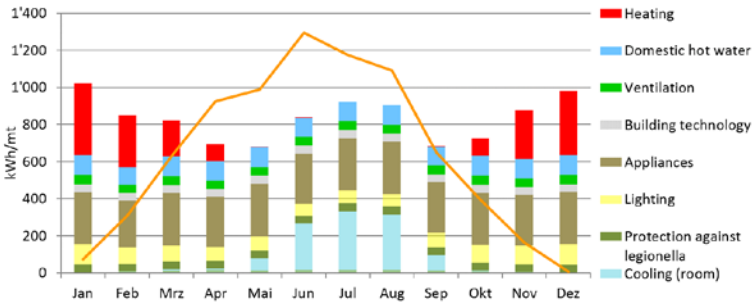


Fig. 4: Example of displayed results for monthly electricity demand by usage and PV-production

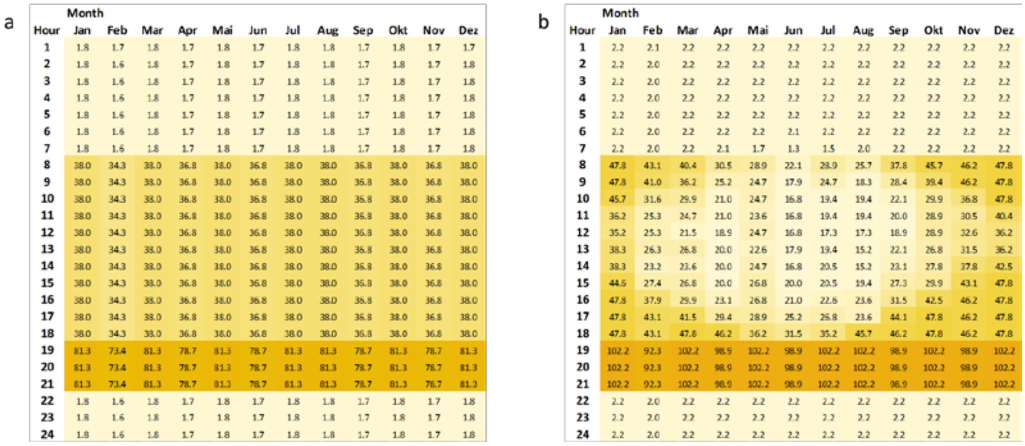
The plausibility can be easily checked via a detailed display of monthly demand values (Fig. 4). This diagram also gives a very good overview of the demand distribution across individual consumers involved.

3. Load profiles for lightening: adaption to daylight

Load profiles according to [4] do not respect the influence of daylight. Therefore, an additional criterion for daylight is implemented in PVopti to distribute demand for lighting more realistically.

According to [4], apartment buildings are comprised of 90% “living apartment building” and 10% “staircase”. Electric lighting is used for 4 hours with full load during daytime (7-18h) for “living apartment building” (11h for ”staircase”) and for 3 hours (2h for “staircase”) with full load during nighttime (18-7h). For special categories like “residential rooms”, nighttime electrical lighting is restricted to the hours between 18-21h. Profiles according to Merkblatt SIA 2024 [4] allocate the same load to each weekday and to each hour in the same daily interval (daytime, nighttime, nighttime restricted, see Fig. 5a).

In PVopti, these load profiles are improved with a criterion for daylight. It is assumed that there is no need for electric light when the global irradiation exceeds 200 W/m^2 (see also [8]). Because there are room types without daylight (e.g. cellar) and room types with shading devices due to necessity (e.g. offices typically have blinds as glare protection or for solar control), the daylight criterion is not used for all rooms. For each building type, a percentage of rooms is assumed to require electric light independent of daylight conditions. For apartment buildings, this percentage is set to 40%. In Fig. 5b the influence of the criterion for daylight on the distribution of the electric load for lighting is shown for an example apartment building (1600 m^2, electric load for lighting: 5 kWh/m^2).



a

	Month											
Hour	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
1	1.8	1.7	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.7
2	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
3	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
4	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
5	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
6	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
7	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
8	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
9	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
10	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
11	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
12	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
13	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
14	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
15	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
16	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
17	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
18	38.0	34.3	38.0	36.8	38.0	36.8	38.0	38.0	36.8	38.0	36.8	38.0
19	81.3	73.4	81.3	78.7	81.3	78.7	81.3	81.3	78.7	81.3	78.7	81.3
20	81.3	73.4	81.3	78.7	81.3	78.7	81.3	81.3	78.7	81.3	78.7	81.3
21	81.3	73.4	81.3	78.7	81.3	78.7	81.3	81.3	78.7	81.3	78.7	81.3
22	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
23	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8
24	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8

b

	Month											
Hour	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
1	2.2	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
2	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
3	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
4	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
5	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
6	2.2	2.0	2.2	2.2	2.2	2.1	2.2	2.2	2.2	2.2	2.2	2.2
7	2.2	2.0	2.2	2.1	1.7	1.3	1.5	2.0	2.2	2.2	2.2	2.2
8	47.8	43.1	40.4	30.5	28.9	22.1	28.9	25.7	37.8	45.7	46.2	47.8
9	47.8	41.0	36.2	25.2	24.7	17.9	24.7	18.3	28.4	39.4	46.2	47.8
10	45.7	31.6	29.9	21.0	24.7	16.8	19.4	19.4	22.1	29.9	36.8	47.8
11	36.2	25.3	24.7	21.0	23.6	16.8	19.4	19.4	20.0	28.9	30.5	40.4
12	35.2	25.3	21.5	18.9	24.7	16.8	17.3	17.3	18.9	28.9	32.6	36.2
13	38.3	26.3	26.8	20.0	22.6	17.9	19.4	15.2	22.1	26.8	31.5	36.2
14	38.3	23.2	23.6	20.0	24.7	16.8	20.5	15.2	23.1	27.8	37.8	42.5
15	44.6	27.4	26.8	20.0	26.8	20.0	20.5	19.4	27.3	29.9	43.1	47.8
16	47.8	37.9	29.9	23.1	26.8	21.0	22.6	23.6	31.5	42.5	46.2	47.8
17	47.8	43.1	41.5	29.4	28.9	25.2	26.8	23.6	44.1	47.8	46.2	47.8
18	47.8	43.1	47.8	46.2	36.2	31.5	35.2	45.7	46.2	47.8	46.2	47.8
19	102.2	92.3	102.2	98.9	102.2	98.9	102.2	102.2	98.9	102.2	98.9	102.2
20	102.2	92.3	102.2	98.9	102.2	98.9	102.2	102.2	98.9	102.2	98.9	102.2
21	102.2	92.3	102.2	98.9	102.2	98.9	102.2	102.2	98.9	102.2	98.9	102.2
22	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
23	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
24	2.2	2.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

Fig. 5: (a) Electric load (kWh) for lightning according to Merkblatt SIA 2024 [4]; (b) Electric load (kWh) for lightening according to [4] improved with a criteria for daylight

Due to the number of days per month, the electric load for lighting per month according to [4] varies between 7.7% (February) and 8.5% (several months, e.g. July) of the yearly load (Fig. 6a). After introduction of the improved model with the criterion for daylight, the distribution changes (e.g. June has 6.8% and December 10.2% of the yearly load, Fig. 6b).

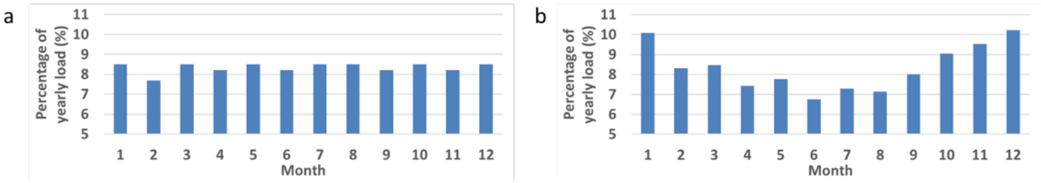


Fig. 6: Percentage of yearly load for lightening per month (a) according to Merkblatt SIA 2024 [4]; (b) improved with criteria for daylight

4. Validation

Assumptions and calculations are the same as for the precursor tool "Enerflex", validation of Enerflex (see [8]) is applicable to PVopti. As mentioned, a comparison to "Solarstromspeicher-Unabhängigkeitsrechner" [10] shows a high correlation in the results. As stated above, introduction of the criterion for daylight leads to a significant change in the household demand (see Fig. 6a) into to a yearly profile with higher demand in wintertime (Fig. 6b) leading to a better correlation with the demand generated with daily load profiles according to "Stromlastprofil H0, BEDW" [9].

For validation purposes, further calculations done with PVopti and measurement results are compared for seven buildings (see Fig. 7). For each building, two calculations are compared to one measurement. The green columns show the result values for the self-consumption ratio and the blue columns show the results for the autarky ratio. The three results are firstly “PVopti” (PO): grid interaction calculated with PVopti based on input available in the early planning phase or as part of the building permit - this calculation is also the basis for Minergie submission. Secondly “Measurement” (MS): based on measured grid interaction and thirdly “PVopti (validated)” (POV): grid interaction calculated with PVopti and input data validated with measured values for demand and production.

For PO, following values are used as input: monthly demand for heating according to SIA 380/1[7], monthly PV-production (simulation with various software) and yearly demand for lighting, appliances and building equipment based on Minergie [5]. Reductions for efficient equipment as permitted by Minergie are not taken into account. If available, additional input is used (e.g. calculation of demand for lighting for kindergarten according to [11], WPesti [12] used for calculation of JAZ, information about operating times for heat production, …). The results of MS are based on billings for electricity and/or on measurements of demand and production. Depending on available data, for POV input values validated by measurement are used. Thereby, the influence of standard values for demand is reduced (as long as the demand of each component is unknown, the distribution of known demand to the components is still influenced by assumptions and standard values).

Because only buildings with available data from building code calculations and measurements can be compared, a small sample consisting of four single-family houses, two apartment buildings and one kindergarten was analyzed. For three buildings (two single family (SFH), one apartment (AB)), measured data spanning two years were available. In Fig. 7, results for each yearly data set are shown. Therefore, there are six single-family house result sets and three result sets for apartment buildings.

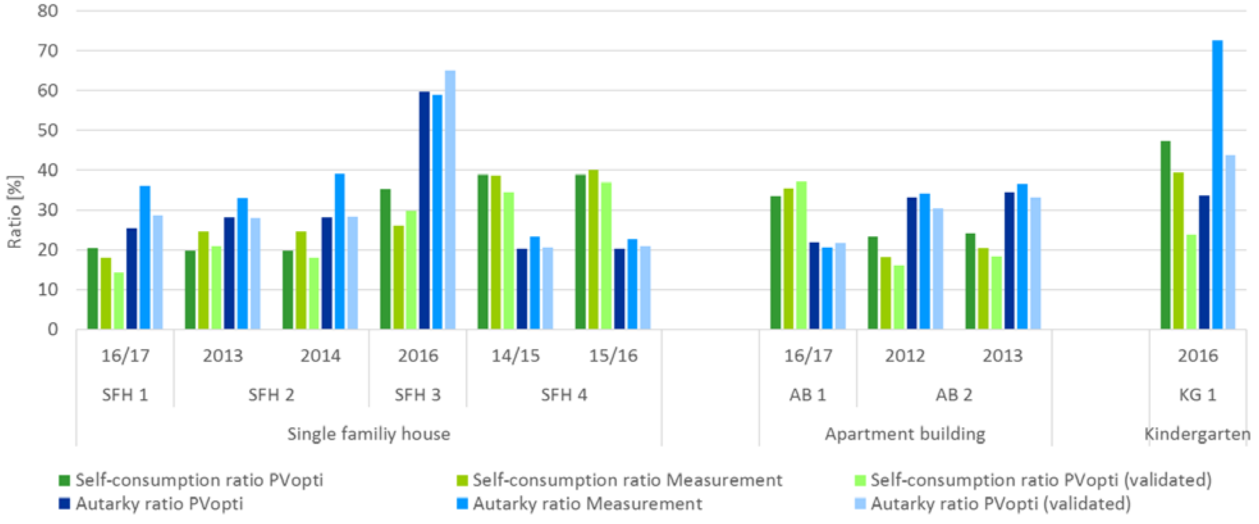


Fig. 7: Comparison of calculation with PVopti and measurement for several buildings

For single family houses, the average difference for the self-consumption ratio between PO and “Measurement” is 3.8% (standard deviation 3.2%), between MS and PVO 4.2% (standard deviation 1.2%). The standard values for total electricity demand (according to [5]) are higher than the measurement values (average 13%), the measured production is about 11% higher than the simulation predicts. Indicated by the reduction of the standard deviation by using validated input data, the results from POV are closer to the measurement values. Due to the electricity storage in one single-family house, the autarky of this building is much higher compared to the others. This indicates that the calculation of an electricity storage in PVopti works well.

For apartment buildings, the average difference for the self-consumption ratio between PO and MS is 3.6% (standard deviation 1.6%) and between MS and POV 1.9% (standard deviation 0.2%). The difference between standard demand values and measured demand is much higher than for single-family houses: about 17%. The difference between measured and predicted values for production is much smaller: 3%. Because of the very low total demand (measurement) of AB2, the difference for electricity demand is above average.

For the kindergarten, the difference in demand between PO and MS is about 62 % which explains the difference in the autarky ratio (PO to MS: 39%). Due to the installed metering system (balancing meters), discrete data for demand and production is not available. Therefore, a simulation for production was necessary to be able to calculate the total demand. Differences between actual PV production and simulated values have a double impact on the derived results for self-consumption. This could be one reason for the big differences between PO and MS The use of standard values of the category “school” for kindergarten (according to [7]) may be another.

5. Conclusion

The limited number of necessary input data and the easy use make PVopti a very good early design tool. In addition, it can be used to calculate the effects of variations like changes of equipment for heat production, introduction of demand-side management, inclusion of an electricity storage or change of PV system size. For single family houses and apartment buildings, the result agreement between standard values according to [5] and measurements is good. Even better agreement is achieved when the demand reduction for efficient equipment is taken into account. The results for self-consumption and feed-in to the grid can be used for cost accounting of variations.

Acknowledgements

PVopti is based on Enerflex, the development of which was funded by the Swiss Federal Office of Energy SFOE under contract number BFE SI/501240 as a contribution to IEA Annex 67 Energy Flexible Buildings. Minergie, the Swiss cantons and the Swiss Federal Office of Energy SFOE, funded the development of PVopti.

References

[1] A. G. Monika Hall, Falk Dorusch, “Optimierung des Eigenverbrauch s, der Eigendeckungsrate und der Netzbelastung von einem Mehrfamiliengebäude mit Elektromobilität,” 2014.

[2] SIA 380, “Grundlagen für energetische Berechnungen von Gebäuden.” 2015.

[3] Merkblatt prSIA 2031, “Energieausweis für Kantone.”

[4] Merkblatt SIA 2024, “Raumnutzungsdaten für die Energie- und Gebäudetechnik.” 2015.

[5] Minergie Schweiz, “Produktereglement zu den Gebäudestandards Minergie/Minergie-P/Minergie-A,” vol. 2017.1, 2017.

[6] Merkblatt SIA 2028, “Klimadaten für Bauphysik , Energie- und Gebäudetechnik SIA-Merkblätter,” no. 2010, 2010.

[7] SIA 380/1, “Heizwärmebedarf.” 2016.

[8] G. A. Hall M., Burger B., “Entwicklung eines Planungsinstruments zur Bestimmung der Netzinteraktion von Gebäuden,” *19. Status-Seminar «Forschen für den Bau im Kontext von Energ. und Umwelt»*, 2016.

[9] Www.new-netz-gmbh.de, “Stromlastprofil H0, BEDW.”

[10] V. Quaschning, “Solarstromspeicher-Unabhängigkeitsrechner.” [Online]. Available: https://www.volker-quaschning.de/software/unabhaengig/index.php.

[11] SIA 380/4, “Elektrische Energie im Hochbau,” 2006.

[12] A. Huber, “WPesti.”